Study of the η meson production with the polarised proton beam

P Moskal, M Hodana

Institute of Physics, Jagiellonian University, PL-30059 Cracow, Poland

E-mail: `p.moskal@uj.edu.pl`

Abstract. The azimuthally symmetric WASA detector and the polarised proton beam of COSY, enable investigations of energy and angular dependence of the beam analysing power in the $pp \rightarrow pp\eta$ reaction. The aim of the studies is the determination of the partial wave contributions via interference terms which are inaccessible from spin averaged observables. The partial wave decomposition is mandatory for the understanding of the reaction dynamics and for the determination of the η-proton interaction, independently of the theoretical paradigm used.

1. Introduction

In the low energy regime of Quantum Chromodynamics, the interaction between quarks and gluons cannot be treated perturbatively and so far the understanding of the processes governed by the strong forces is unsatisfactory. Therefore, it is essential to carry out measurements involving the production and decay of hadrons and to interpret them in the framework of effective field theories experiencing recently an enormous development in applications to the description of meson decays and production. In this contribution we concentrate on the η meson. The progress in understanding of the production processes of the η meson will strongly rely on the precise determination of spin and isospin observables.

2. Partial Waves

Independently of the theoretical framework used, for an unambiguous understanding of the production process relative magnitudes from the partial waves contributions must be well established. This may be achieved by the measurement of the analysing power which would enable to perform the partial wave decomposition with an accuracy by far better than resulting from the measurements of the distributions of the spin averaged cross sections. This is because the polarisation observables can probe the interference terms between various partial amplitudes, even if they are negligible for the spin averaged distributions. More importantly, in the case of the $pp \rightarrow ppX$ reaction, as pointed out in reference [1, 2], the interference terms between the transitions with odd and even values of the angular momentum of the final state baryons are bound to vanish for the cross sections. This characteristic is due to the invariance of all observables under the exchange of identical nucleons in the final state. Due to the same reason there is no interference between s and p-waves of the η meson in the differential cross sections [2]. However, s-p interference does not vanish for the proton analysing power, and thus the precise

measurements of A_y could provide the first determination of the comparatively small p-wave contribution [2], unreachable from spin averaged observables.

In the last decade a vast set of the unpolarised observables has been established at the facilities CELSIUS, COSY and SATURNE for η production in the collision of nucleons. The data comprise in principle a lot of interesting information concerning the production mechanism and the η-nucleon interaction. These, however, could have not been derived unambiguously due to lack of the knowledge about the relative contributions from the partial waves involved.

3. Presently avaiable data

The present poor data base of the polarisation observables only allows for qualitative conclusions.

In order to establish quantitatively contributions from various production processes and to determine possible interference terms more precise measurments of the spin observables and more support from the theoretical side is needed.
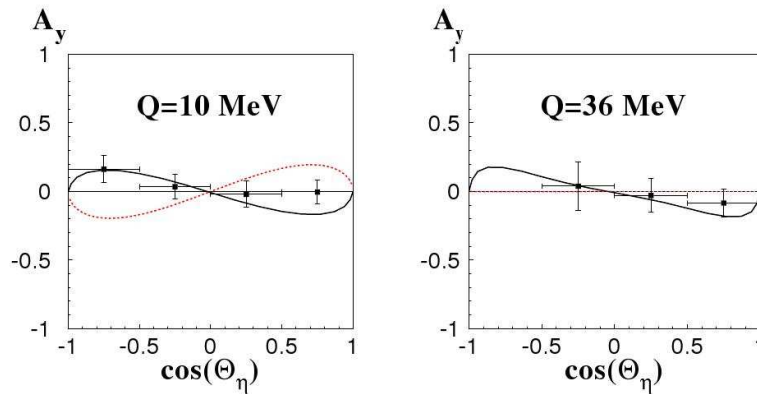

Figure 1. Analysing powers for the $\vec{p}p \to pp\eta$ reaction as functions of $\cos\theta_\eta$ for Q = 10 MeV (left panel) and Q = 36 MeV (right panel) obtained by the COSY-11 collaboration [3,4]. Full lines are the predictions based on the pseudoscalar meson exchange model [5] whereas the dotted lines represent the calculations based on the vector meson exchange model [6]. Shown are the statistical uncertainties solely.

So far measurements of the analysing power for the $\vec{p}p \to pp\eta$ reaction have been performed in the near threshold energy region at excess energies of Q = 10 and 36 MeV at COSY by the COSY-11 collaboration [3,8], and at higher energies for Q = 324 MeV, Q = 412 MeV and Q = 554 MeV at SATURNE by the DISTO collaboration [7]. For all studied energies, the determined analysing power is essentially consistent with zero implying that the η meson is produced predominantly in s-wave. The achieved statistics, as shown in figures 1 and 2, allowed for only a rough determination of the angular dependence with four and five bins and the errors of A_y equal to ± 0.1 and ± 0.2, respectively.

Using the WASA-at-COSY facility we intend to determine the energy and angular dependence of $A_y(Q,\theta)$ and the total and differential cross sections for the $pp \to pp\eta$ reaction in the excess energy range from the threshold up to 100 MeV. In November 2010 first measurement for Q = 15 MeV and Q = 72 MeV have been conducted [9] .

4. Dynamics of the pp → ppη reaction

Precise data sets [10–17] on the total cross section of η meson production in the $pp \to pp\eta$ reaction allowed to conclude that the reaction proceeds through the excitation of one of the protons to the $S_{11}(1535)$ state which subsequently deexcites via emission of the η meson. The crucial observations were a large value of the absolute cross section (forty times larger
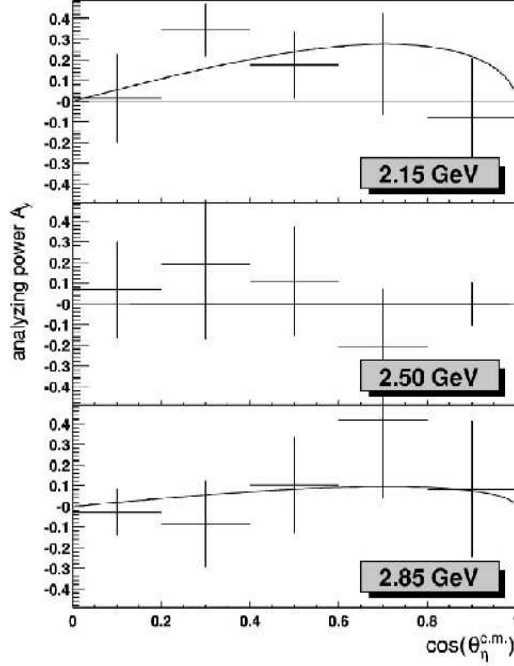
Figure 2. Analysing power for the $\vec{p}p \to pp\eta$ reaction as functions of $\cos\theta_\eta$ for Q = 324 MeV (upper panel), Q = 412 MeV (middle panel) and Q = 554 MeV (lower panel) obtained by the DISTO collaboration [7]. The solid curves are fits to the data using a formula based on ρ meson exchange [6]. The figure is adapted from [7].

than for the η' meson) and isotropic distributions [17–19] of the η meson emission angle in the reaction center-of-mass system. More constraints to the theoretical models [5, 6, 20–25] have been deduced from the determination of the dependence on the isospin of the colliding nucleons [26]. The experiments performed by the WASA/PROMICE collaboration [26] revealed a strong isospin dependence confirmed at threshold by the COSY-11 group [27,28]. All together, the confrontation of predictions based upon different scenarios, involving exchanges of various mesons, with the so far determined unpolarised observables and with the first results on the analysing power indicate the dominance of π exchange in the production process [3]. This conclusion is in line with the predictions of Nakayama et al. [5] and also recent calculations of Shyam [29]. Yet, the implications seem to be contra-intuitive due to the very large momentum transfer between the interacting nucleons needed to create the η meson near threshold. A poor data base of polarisation observables allows, however, only for qualitative conclusions. To establish quantitatively contributions from various production processes and to determine possible interference terms more precise measurements of the spin observables are needed. Another very interesting feature of $pp \to pp\eta$ reaction is the difficulty in reproducing the pp invariant mass distributions [16, 19, 30, 31]. Calculations which include NN FSI and $N\eta$ FSI do not match existing data [19]. To explain the unexpected shape of the distribution, possibility of higher partial-waves is considered. Taking into account a P-wave contribution one could reproduce the pp invariant mass distribution but not the close to threshold cross section dependencies [32]. To solve this discrepancy, a D_{13} resonance has been included [33]. In the calculations, however, the data collected so far are insufficient for the unambiguous extraction of the S-wave or P-wave contributions.

High statistics data collected by the WASA-at-COSY detector should enable a study of the evolution of the analysing power as a function of the invariant mass spectra of the two particle

subsystems. This would shed a light on the still not explained origin of structures in the invariant mass distributions observed independently by the TOF [16], COSY-11 [19, 31], and CELSIUS/WASA [30] collaborations. It is worth to stress that similar shapes of the invariant mass distributions have been also observed recently in the case of the η' meson [34]. In both the η and the η' case the intricate structure remains so far unexplained.

5. Studies of A_y with the WASA-at-COSY detector

For the measurements of the beam analysing power of the $\vec{p}p \rightarrow pp\eta$ reaction we use the axially symmetric WASA-at-COSY experimental setup [35] working as an internal target facility at the cooler synchrotron COSY [36, 37]. A vertically polarised proton beam [38], is stored and accelerated in the COSY ring. The direction of the polarisation is flipped from cycle to cycle. The beam of hydrogen pellets cross the circulating COSY beam in the center of the WASA detector. Protons from the $pp \rightarrow pp\eta$ reaction are registered in the Forward Detector and the gamma quanta from the η meson decay are detected in the electromagnetic calorimeter. Both the invariant mass of the decay products and the missing mass to the outgoing protons are used for the identification of the η meson. The determination of the beam polarisation and the control of the systematics is achieved by measuring the asymmetries for elastically scattered protons for which precise values of the analysing powers are available [39]. The accuracy of these results is 1.2% and will allow to control the systematic error of the polarisation determination to about 1%.

Based on the online monitoring of the first measurement of the $pp \rightarrow pp\eta$ reaction performed with WASA-at-COSY, the beam polarization achieved in this experiment amount to $\sim 70\%$ and $\sim 60\%$, for measurements with Q= 15 MeV and Q = 72 MeV, respectively.

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